

DEVELOPMENT OF A LASER-BASED ALIGNMENT SYSTEM UTILIZING FRESNEL ZONE PLATES AT THE KEKB INJECTOR LINAC

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Abstract

A new laser-based alignment system utilizing Fresnel zone plates (FZPs) is under development in order to precisely align accelerator components along an ideal straight line at the KEKB injector linac. We experimentally investigate focusing and propagation characteristics of a He-Ne laser passing through a laser pipe under an effect of the laser reflection and scattering from the inner surface of the pipe at atmospheric pressure. In a case of the large effect, it may cause the reduction of the alignment precision. In this report, the experimental focusing and propagation characteristics of the laser utilizing circular FZPs at the focal region are described in detail.

INTRODUCTION

There has been renewed interest in the study of high-precision alignment techniques, particularly with the aim of applying them to high-energy particle accelerators [1]. The development of alignment techniques is essential for long-distance injector linacs not only for stabilizing the acceleration and transportation of particle beams with higher charge intensities, but also for preserving the beam quality and enhancing the injection efficiency of the beams into the storage rings.

The SuperKEK B-Factory (SuperKEKB) project [2] is the next generation of B-factories under construction at KEK after the KEK B-Factory (KEKB) project [3], which was stopped in 2010. SuperKEKB is an asymmetric electron-positron collider comprising 4-GeV positron and 7-GeV electron rings. Because SuperKEKB is a factory machine, well-controlled operation and high-precision alignment of the KEKB injector linac [4] are indispensable to maintaining the injection rate, stability of the beam collision, and peak luminosity as high as possible.

A conventional laser-based alignment technique involving fourfold segmented silicon photodiodes (PDs) has been developed for the 600-m-long injector linac at KEK [5]. This alignment technique has an advantage over other techniques due to its relative simplicity. The suitably focused laser beam is directly detected by a fourfold-segmented photodiode, which measures the gravity center of the intensity distribution in the transverse directions in the alignment measurement. However, this system requires more photodiodes with increasing the length of the linac. In general, since these photodiodes are installed just below the beam line, they

may easily suffer heavy damage due to hard radiation during long-term accelerator operation [6]. This is the reason that we develop the new laser-based alignment system with FZPs. This new technique may be practically free and robust from radiation damage even under long-term accelerator operation because it uses FZPs as the optical reference targets in the alignment measurement [7].

However, there are several difficulties to replace our present laser-based alignment system with PDs to the new one. One of main difficulties is that the diameter of a laser pipe is so small that it is not easy to propagate a laser beam with a divergence angle, which needs to propagate in vacuum in order to irradiate the whole transverse area of the FZP. The propagation of such the laser beam may cause unnecessary reflection and scattering from the inner surface of the laser pipe. Moreover, this effect may deteriorate the focusing characteristics of the laser beam, and it may reduce the alignment precision. This is a main reason to investigate the experimental focusing and propagation characteristics of the laser beam with a large divergence angle utilizing circular FZPs at the focal region.

EXPERIMENTAL SETUP

Optical configuration for the laser propagation

Systematic experiments were performed for studying the focusing characteristics and laser propagation in the beam line (sector C) at the KEKB linac [4]. The optical configuration and experimental setup are shown in fig. 1.

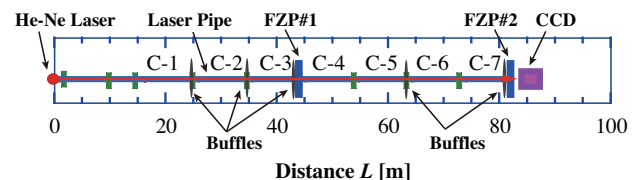


Figure 1: Optical configuration and experimental setup.

A light source is a commercially available 1-mW He-Ne laser having a wavelength of 632.8 nm at atmospheric pressure. The waist position of the laser beam is just out of the laser source and the waist size is ~ 1.5 mm considering the full width at half maximum (FWHM). The transverse beam size of the laser is expanded with two concave lenses (focal length: $f=50$ mm and $f=1000$ mm) successively mounted on an optical table along with the laser source. The laser beam with a divergence angle

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beam line one-by-one. We confirmed the gradual intensity reduction for these two lines. This means that relatively hard scattering of the laser beam with a shallow angle to the inner surface of the laser pipe was produced. On the other hand, the sprinkled speckle patterns did not change even after installing the baffles. This means that the laser halo might be truncated by the pipe diameter due to the relatively weak scattering.

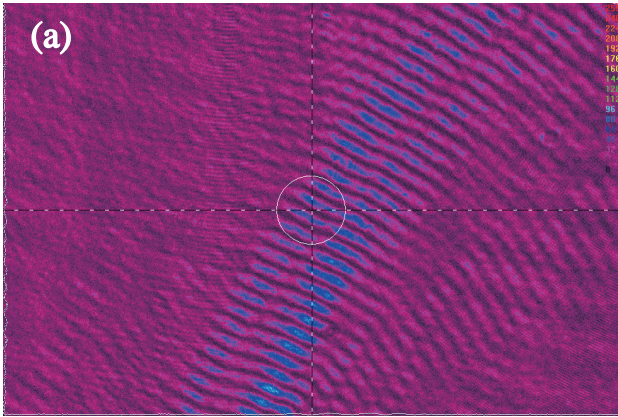


Figure 3: Typical background images of the laser beam (a) without any baffles and (b) with five baffles obtained at the focal region without any FZPs. In this measurement, the gain of the CCD camera was set to be 16 dB.

Figure 4: Typical focused spot image of the laser beam with the FZP2 obtained at the focal region. The solid circle (white) with a diameter of 5 mm indicates the analyzed area, and the solid lines (white) indicate the

projected intensity distributions in the horizontal (x) and vertical (y) directions. The gain of the CCD camera was set to be 1 dB.

The focused spot images for the FZP1 and FZP2 were clearly obtained at the focal region. The spot widths (4-'' size) for the FZP1 (FZP2) were measured to be $W_x \sim 1.64$ (0.38) mm and $W_y \sim 1.43$ (0.38) mm, which are consistent with calculations. Figure 4 shows the focused spot image obtained for the FZP2. After the gain correction calculation of the camera, the signal-to-noise (S/N) ratio of the peak intensity in the intensity distribution is ~ 39 (~ 63) for the FZP1 (FZP2). In this measurement, after the insertion of the vacuum glass windows, the background levels without any FZPs were much the same, while the focused spot width became slightly wider and the peak intensity was also slightly reduced.

Based on these measurements, the background levels of the laser beam could be sufficiently suppressed without disturbing the intensity distribution of the focused spot image with adequate S/N ratio required for the alignment measurement. In actual optical setup, since the vacuum condition in the laser pipes is adequately kept, it is expected for further brightness increase in the peak intensity of the laser beam.

SUMMARY

Systematic experimental investigation on the focusing and propagation characteristics of a He-Ne laser using circular Fresnel zone plates has been successfully performed at atmospheric pressure.

When the laser beam with a divergence angle of 1.7 mrad propagates through the laser pipe along the beam line, the scattering and reflection of the laser beam from the inner surface of the pipe occur, and however, it is understood that they can be sufficiently reduced with the use of several baffles. However, it is difficult to fully remove sprinkled speckles produced by the laser scattering, which may indicate the surface roughness of the laser pipe coated with a black paint composed of acrylic resin.

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